



National Weather Service

Phoenix, AZ

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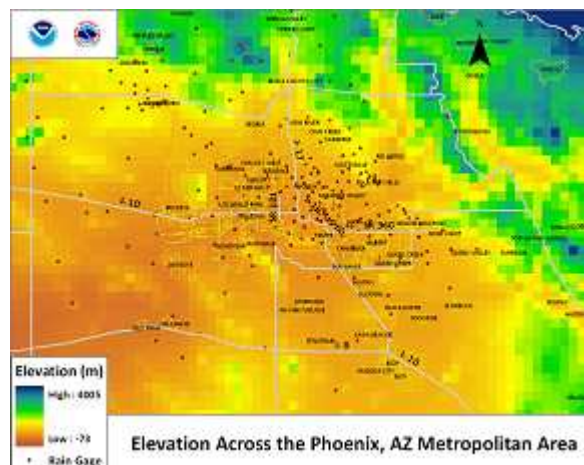
Does the Urban Heat Island Affect Rainfall Variability Across the Phoenix, AZ Metropolitan Area During the Monsoon Season?

Introduction

The Phoenix, AZ Metropolitan Area (PMA) covers a large area of the lower Salt River Valley in central Arizona. It lies on the northeast fringes of the Sonoran Desert and borders the foothills which lead to the Mogollon Rim to the northeast (Figure 1, below). Elevation in the metropolitan area itself ranges from 340 m (1115 ft) near the Salt River to well over 1200 m (3900 ft) at the summit of the White Tank Mountains. Lower elevations generally continue to the west and south as the region opens into the Sonoran Desert.

Table 1. Population of the Phoenix Metropolitan Area (U.S. Census Bureau, 2008).

Year	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000	2006
Population (in thousands)	28	44	106	173	215	375	726	1,035	1,670	2,238	3,252	4,039



According to the City of Phoenix's Website, the population of Phoenix in 1881 was roughly 2,500. Today, the population of the PMA is near 4.2 million (*see Table 1*) (U.S. Census Bureau, 2008). By 2030, the population is projected to be 7.3 million (Maricopa Association of Governments, 2005). This large and mostly rapid growth has resulted in the creation of a significant urban heat island (UHI). But has the development of the UHI led to a change in convective (i.e. thunderstorm) precipitation patterns across the PMA during the monsoon season? To date, no research has conclusively

proven that the UHI has altered precipitation patterns across the PMA. However, a growing body of research exists that supports the notion that the PMA is enhancing precipitation in *downwind* (to the northeast) areas. Data presented on this page will illustrate that there is no coherent patterns in precipitation across the PMA which cannot be explained by topographic influences.

The Urban Heat Island

The mechanisms which lead to the creation of an urban heat island (UHI) have been studied for nearly a century and are well understood. Like many other large cities, the PMA has a substantial UHI. As early as 1921, urban effects on the local climate in Phoenix, Arizona were recognized. Analyzing winter-time minimum temperatures in the Salt River Valley, Gordon (1921) found that the weather station in Phoenix, which at the time was roughly two percent of its current population, was warmer than expected for a low-valley location. He noted that the “Riverside Nursery is protected on the north by both the diversion of the cold air stream and by the city of Phoenix itself with its warming influence,” likely making him the first scientist to describe the Phoenix UHI. Since that time, the population has increased nearly 40-fold, resulting in an intensification and expansion of the UHI.

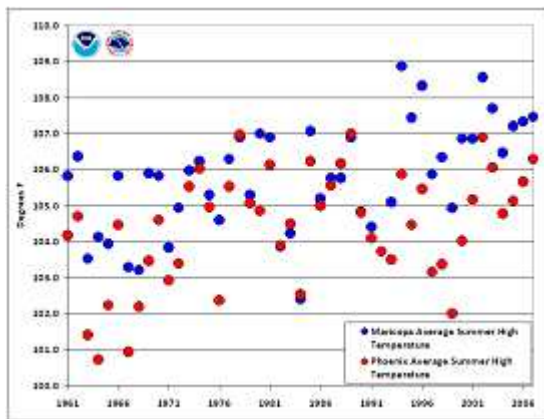


Fig. 2. Average summer (June-July-August) high temperatures for Phoenix and Maricopa. Little difference can be noted between the two datasets.

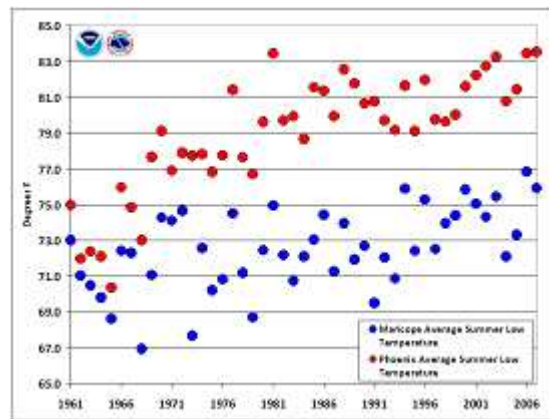


Fig. 3. Average summer (June-July-August) low temperatures for Phoenix and Maricopa. A steady upward trend can be seen in both datasets, though Phoenix became considerably warmer than Maricopa during the late 1960s through late 1980s.

The effects of the UHI are most pronounced during the summer (June-July-August) months. In a simple comparison, average high and low temperatures from Maricopa, AZ and Phoenix Sky Harbor International Airport were compared (Figures 2 and 3). Little difference exists between the high temperatures from 1961 through 2007; however, low temperatures have trended warmer at Sky Harbor as compared to Maricopa, indicative of the existence of a strengthening UHI. Similar results have been found by Brazel et al. (2000), who compared temperature observations at several urban stations in the PMA (Phoenix, Mesa, and Tempe) to a rural station outside the PMA (Sacaton). The average minimum May temperature at the urban locations displayed an apparent upward increase through the time series (1910 through 2000), which was attributed to the urban growth of the region. By the end of the series, there was a +4 to 7 °C (7 to 13 °F) difference between the urban minimum temperatures and the rural minimum temperatures. Interestingly, no upward trend was found in the maximum temperatures, and in fact, the urban temperatures were consistently 0 to 2 °C (0 to 4 °F) cooler than the rural station. The hypothesized reason for this is the “oasis effect”, where solar energy

is expended on evaporating water from an unnaturally moist surface in the urban areas due to irrigational activities.

Anthropogenic Effects on Precipitation

The effects of urban heat islands (UHIs) on rainfall patterns have been anecdotally noted since at least the early 20th century. Horton (1921) described the tendency for cities to be “thunderstorm-breeding spots” – places which he observed as being favorable for thunderstorm development. While the notion that cities can have a direct impact on precipitation patterns has existed since the early 20th century, it was not until the late 1960s that the topic gained widespread interest. In an analysis of precipitation variables in and around the Chicago, Illinois area, Changnon Jr. (1968) described a statistical anomaly that existed downwind of Chicago, near the town of La Porte, Indiana. Compared to other nearby stations in the dataset, La Porte had experienced a 31 percent increase in annual precipitation, a 28 percent increase in warm-season precipitation, a 34 percent increase in the number of heavy rain days, and a 38 percent increase in the frequency of thunderstorms. Through an exhaustive analysis of the data, the author was able to eliminate a number of potential sources of error and concluded that the “La Porte Anomaly” was a reality. The source of the anomaly was attributed to an increase in cloud condensation nuclei (CCN) released by an industrial complex which lay upwind of La Porte.

There are generally four agreed upon human-caused mechanisms in which urban areas alter nearby precipitation fields. The first is the addition of sensible heat due to the change in thermal properties associated with the transformation of the landscape (Lowry, 1998; Oke, 2005). This often results in the formation of thermal updrafts over urban areas and is indicative of the urban heat island. Second is the addition of latent heat to the lower atmosphere through anthropogenic activities such as irrigation (Diem and Brown, 2003; Dixon and Mote, 2003). Third is an increase in surface convergence due to an increase in surface roughness associated with urban structures (Loose and Bornstein, 1977; Bornstein and Lin, 2003). The fourth mechanism is pollution. Pollution particles, such as sulfates, can act as cloud condensation nuclei (CCN) that can either promote or retard the growth of water droplets, depending on the structure and physical/chemical properties of the CCN (Gatz, 1974; Salby, 1996; Rosenfeld, 2000)

Since the discovery of the La Porte Anomaly, many studies have been published which attempt to quantify to what extent cities influence local rainfall, several of which are specific to central Arizona. Diem and Brown (2003) acquired precipitation data from several widely scattered rain gages in central Arizona. A trend analysis of the data, from 1950 through 2000, yielded an increase in precipitation at a handful of stations in the Lower Verde River basin. Similar results were found by Shepherd (2006) utilizing a longer dataset bifurcated into two periods, a pre-urban (1900-1950) and post-urban (1950-2000). Satellite-based RADAR data was also used, with similar results to previous research. The common theme to this research was an increase of precipitation *downwind (to the northeast)* of the Phoenix Metropolitan Area (PMA).

No research studies have been published in the scientific community which specifically addresses the alteration of precipitation across the PMA itself.

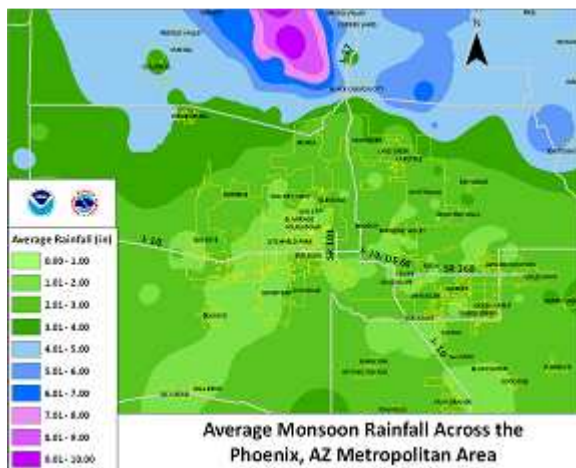


Fig. 4. Average precipitation across the Phoenix, AZ Metropolitan Area during the monsoon season, based on 1998-2007 data from roughly 200 gages.

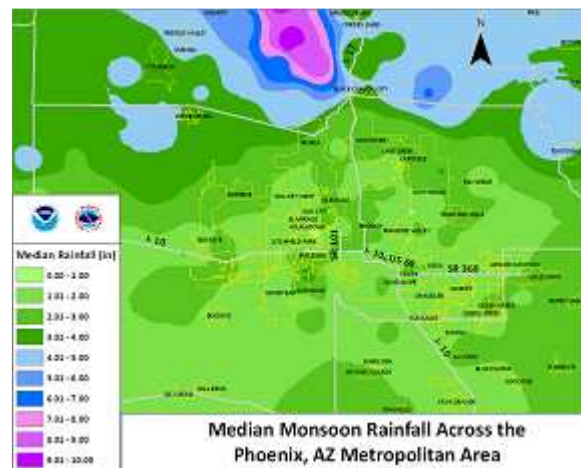


Fig. 5. Median precipitation across the Phoenix, AZ Metropolitan Area during the monsoon season, based on 1998-2007 data from roughly 200 gages.

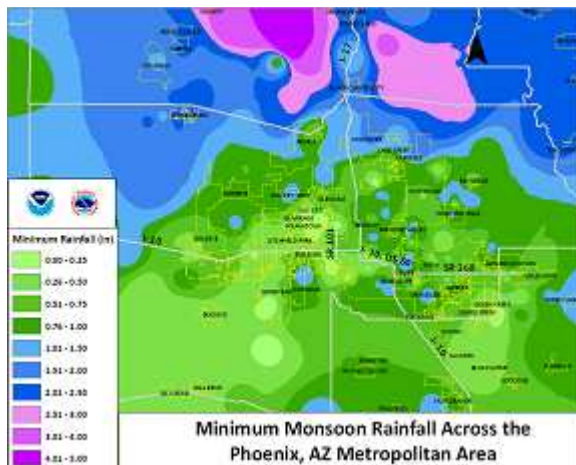


Fig. 6. Minimum monsoon season precipitation during a 10 year period (1998-2007) based on data from ~200 gages.

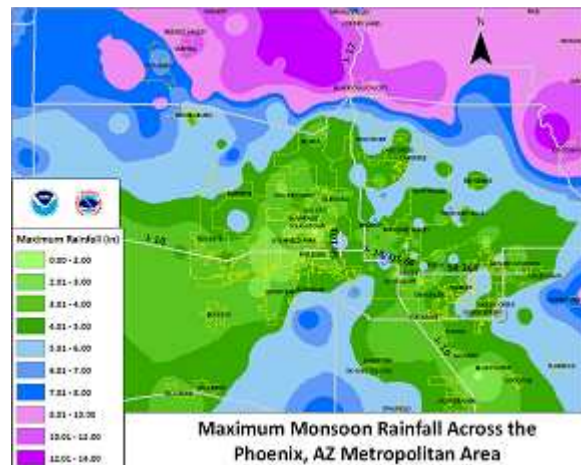


Fig. 7. Maximum monsoon season precipitation during a 10n year period (1998-2007) based on data from ~200 gages.

The rapidly growing PMA represents an interesting yet complex area to study anthropogenic effects on precipitation (AEP). The topography of the PMA is generally flat, but some of the most complex topography in the state resides just 50 to 120 km (30 to 75 mi) to the north to east of downtown Phoenix (Figure 1). The range of mountainous terrain in central Arizona, known as the Mogollon Rim, is a favored area for convective development during the summer and is one of the most active convective areas in the United States (Changnon Jr., 1988). Precipitation amounts during the monsoon season are greatest along and to the southwest of the Mogollon Rim. In addition, Arizona has one of the most unique diurnal evolutions of convection in the United States. Using lightning data, King and Balling Jr. (1994) found that peak lightning activity was constrained to the Mogollon Rim and complex terrain of

southeast Arizona during the mid-afternoon hours. A very late (near midnight) maximum was found over central Arizona, including the PMA. This type of late-night maximum is found in only one other locale in the country (north-central Great Plains). While the precise reasoning for this extraordinary pattern is unknown, it is likely due to a combination of airflow drainage from the mountains into the PMA (Brazel et al., 2005) and thunderstorm convergence. It has been well documented by several researchers that convection will often propagate to the west or southwest from the Mogollon Rim while convection propagates west or northwest from the mountainous area of southeast Arizona, thus converging over the PMA (Watson et al., 1994; McCollum et al, 1995). This process causes precipitation amounts to be greatest generally around the PMA, clockwise from northwest to south, with the relative maximum to the northeast.

Several images have been compiled from nearly two-hundred rain gages across the PMA which are owned and operated by the Flood Control District of Maricopa County. The data used were obtained for the Monsoon Season (June 15th through September 30th) for the years 1998 through 2007. The data are quality controlled, with stations containing excessive missing data removed from the analysis. In addition, data from Phoenix Sky Harbor International Airport have been included. Figures 4 and 5 display the average and median seasonal precipitation across the PMA and nearby areas. Note that the greatest values are to the north of the PMA, with little variability across the urban areas. A strong relationship can be found when comparing average precipitation to elevation (figure 8). Maps displaying the least and greatest rainfall during the monsoon season at each station can be seen in figures 6 and 7, respectively.

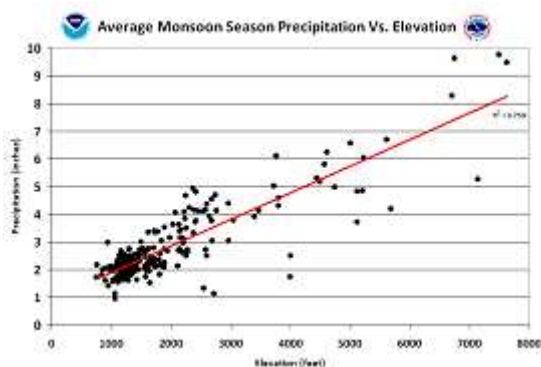


Fig. 8. Average monsoon season precipitation (1998-2007) versus elevation for roughly 200 gages across the Phoenix, AZ metropolitan area.

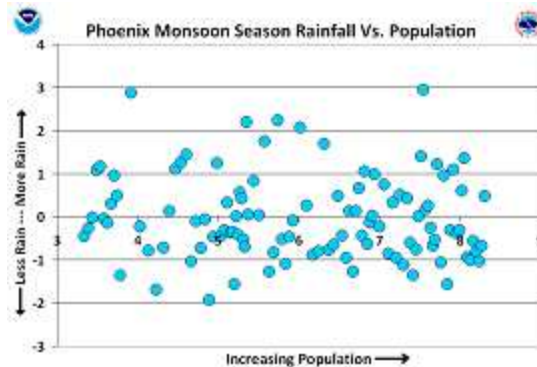


Fig. 9. Standardized precipitation versus standardized population for Phoenix. This graph demonstrates that there is no correlation between an increase in population and a change in monsoon season precipitation in Phoenix.

Another simple analysis which would indicate a change due to a growing population would be the official Phoenix, AZ dataset. While the station has moved a handful of times since its inception in 1895, it has always remained near the center of the city. Therefore, any hypothesized changes due to the growth in urbanized areas should be reflected in the official Phoenix dataset. Figure 9 displays precipitation as a function of population (standardized) during the Monsoon season (June 15 through September 30) from 1896 through 2007. No correlation exists between monsoon season precipitation and population in the 112-year

official Phoenix dataset. Based on the data and information presented here, it can not be concluded that the UHI is impacting precipitation patterns across the PMA.

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